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ORIGINAL ARTICLES.

Tertiary Orbitoids from North-Western Peru.

By J. U. Todd, B.A., and R. Wright Barker, B.A., F.G.S.

(PLATES XXXIX–XLII.)

THE material to be described was collected by one of us while in the service of Lobitos Oilfields, Ltd., and was presented to the British Museum (Natural History). We owe our thanks to the Directors for allowing us to examine and report on the specimens, all of which were obtained from the neighbourhood of Lobitos.

The succession is shown in the table, quoted from information supplied to the British Museum, and is compared with that given by Olsson (14) [1] and Bosworth (4), but is not to be regarded as final. The beds are lenticular and it is not suggested that all these beds are present in any given area, though the publication by the chief geologist, of the results of extensive field work, carried out in the past few years, will, no doubt, do much to elucidate the stratigraphy. We have collected larger foraminifera from the beds marked with an asterisk, but those from the Convento beds are not available for examination; Berry (3) records *Helicolepidina* and *Lepidocyclina* from beds (958 ft. above the base of the Saman shale) which are equivalent to our Convento Beds.

Berry (2) also records *Asterodiscocyclina* from the Terebratula Beds and Tobler (18) *Asterocyclina* from Charaos, about 100 miles south of Lobitos, but these genera are not represented in the present collection.

Discocyclina restinensis sp. nov. (Pl. XXXIX, Figs. 3, 4, 5, 7.)
Syntypes: B.M. No. P. 30215–6, 30218, 30219.

Description.

External Appearance.—The test is circular in outline and umbonate with a thin, slightly undulose flange, the surface being papillate. The papillae are smaller on the umbo than on the flange, an average

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[1] See literature cited at end.

	ft.		Olsson.	Bosworth.
Eocene.	1,000	Red Shales of Restin.	Chira Shale.	Lobitos Formation.
	1,000	* Purple Ssts. and Shales.	3rd Verdun Grit.	
	250	* Cardo Grit.	2nd Verdun Grit.	
	1,000	Media Ssts. and Shales.	1st Verdun Grit.	
	1,100	* Yapato Grit. (Organos Grit.)		
	600	La Cruz Beds.	Pozo Shales.	
	400	Oyster Conglomerate.		
	1,100	Vega Shales.		
	600	Vega Sandstone.	Talara (Saman) Sst.	
	600	Lobitos Blue Ball Sandstone.		
	1,200	Fernandez Shale.	Talara (Saman) Shale.	
		Atascadero Lst.		
	1,000	* Convento Beds.		
	600	Organos Shale.		
	250	* Terebratula Beds.	Saman Conglomerate.	
	300	Nautilus Beds.	Restin Shales.	
	300	Monte Beds.		
	200	Monte Shale.		
	600	Cyclammina Beds.		
	800	Echinocyamus Beds.	Pariñas Sandstone.	Clavelithes Beds.
	250	Cabo Blanco Sst.		
	600	Clavel Shale.	Pale Shales.	
	400	Lagoon Beds.		
	400	Peña Negra Beds.		
	400	Cristellaria Shale.		
	600	* Helicolepidina Sandstone.		
	600	Lower Trochammina Shales.		
	600	* Restin Sands.		
	800	Eponides-Diastoma Shale.		
	250	Lower Caverno Sandstone.		Turritella Beds.

diameter for those on the latter being 110μ. Of four specimens showing the flange with an unbroken periphery an average diameter is 5 mm., with an average diameter of the umbo of 1·2 mm. Specimens consisting of an umbo with the flange broken away give an average diameter of 1·7 mm. varying from 1·2 mm. to 1·75 mm., and an average thickness of 0·78 mm. with a minimum of 0·69 mm. and a maximum of 0·98 mm.

Equatorial sections show that the second embryonic chamber is reniform enclosing more than half the initial chamber (Fig. 3). An average diameter for the initial chamber is 148μ varying from 125μ to 170μ, and an average diameter for the second chamber is 277μ varying from 240μ to 310μ. The total length has an average of 255μ varying from 215μ to 275μ. The first annulus, surrounding the embryonic apparatus, contains from twenty to thirty chambers, and is very narrow tangentially to the outer wall of the initial chamber. The chambers of the equatorial layer are squarish near the centre but show variation near the edge of the dome, the average measurement at about 1 mm. from the centre being 36μ radially by 26μ tangentially. The walls between succeeding annuli show an approximately constant thickness of 11μ and the septal walls do not alternate in successive annuli.

In *transverse section* there are eight to ten layers of lateral chambers which are constant in size over the whole dome, an average measurement being 42μ horizontally and 12μ vertically, and the layers are divided by walls 15μ thick. The equatorial layer is thin and varies but little, being 18μ at the centre and 22μ at the edge of the dome, with covering walls 15μ thick. Numerous pillars are present which thicken rapidly as they approach the surface, terminating in papillae with an average diameter of 75μ.

Tangential sections show that the lateral chambers are irregularly polygonal in outline with an average measurement of about 90μ by 50μ, and divided by walls 7–8μ thick. The pillars have a circular outline with a diameter about 92μ, and are 70–110μ apart.

Comparison.—The species which most closely resembles this appears to be *Discocyclina peruviana* (Cushman), but various slight differences have led us to believe that the two are distinct species. The greater diameter of the second embryonic chamber in *Discocyclina restinensis* is greater than the total length, whereas the reverse is true in *Discocyclina peruviana* (see Table on p. 535). The median layer varies less in thickness, the chambers are less oblong and arranged in more regular annuli, and the second embryonic chamber embraces more of the initial chamber.

Text-Figs. 1 and 2 show the differences in the embryonic apparatus.

Occurrence in Lobitos.—Well samples from the *Helicolepidina* Sandstone, together with *Helicolepidina spiralis* Tobler and *Lepidocyclina vichayalensis* Rutten. Also, unaccompanied, in the top of the Restin Sands.

Helicolepidina spiralis Tobler.

(Pl. XL, Figs. 3, 4.)

1922. *Lepidocyclina* (*Helicolepidina*) *spiralis* Tobler (17), pp. 380–4, figs. 1–3.
1926. *Helicolepidina spiralis* Hodson (11), pp. 6–7.
1932. *Helicolepidina spiralis* v. der Vlerk (23), p. 109, q.v. for further references.

The test is lenticular and papillate over the whole surface. Although sections prove that both megalospheric and microspheric forms are present, they can rarely be distinguished externally in the material available.

In the *megalospheric form* (Pl. XL, Fig. 4) the initial spherical chamber varies in diameter from $90\mu \times 92\mu$ to $115\mu \times 126\mu$, with an outer wall 18μ thick, and a curved septum 10μ thick dividing it from the second chamber. One and a half spirals are shown, marked only by elongated chambers with small chambers just inside the spiral, the other equatorial chambers showing no definite arrangement and varying in shape from ogival to hexagonal.

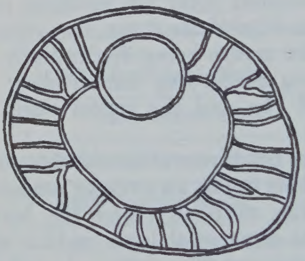


Fig. 1.—*Discocyclina peruviana* (Cushman). Embryonic apparatus. × 92.

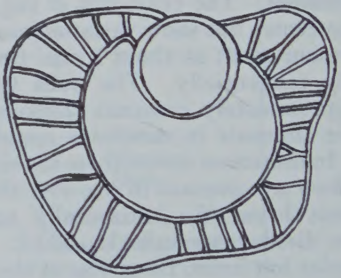


Fig. 2.—*Discocyclina restinensis* sp. nov. Embryonic apparatus. × 100.

In the *microspheric form* (Pl. XL, Fig. 3, Text-Fig. 5) there is a small spherical initial chamber followed by six chambers in the first spiral. The second spiral has a thick wall and contains seven chambers with small chambers in the angles.

Occurrence in Lobitos.—Well samples only, of the *Helicolepidina* Sandstone, together with *Discocyclina restinensis* and *Lepidocyclina vichayalensis* Rutten.

Lepidocyclina (*Polylepidina*) *vichayalensis* Rutten.

(Pl. XL, Figs. 5, 6.)

1928. *Lepidocyclina* (? *Isolepidina*) *vichayalensis* Rutten (15), p. 945, pl. ii, 25–6, text-fig. 24 *f–k*, *n–p*.

The test is lenticular, circular in outline, and pustulate. Sections again prove the presence of megalospheric and microspheric forms, though the megalospheric forms are less abundant in our material.

Equatorial sections of the megalospheric form show a bilocular embryo, in which the chambers are divided by a curved wall, and this is followed by about seven chambers arranged in almost a complete spiral. The total length of the embryo is 270μ, and the greatest width 185μ, these measurements including the embryonic walls, which are 18μ in thickness. The diameter of the initial chamber is $140\mu \times 148\mu$, excluding walls, and of the second chamber $90\mu \times 122\mu$.

Measurements from Rutten's figures give an average total length of 300μ and an average greatest width of 225μ including the embryonic walls, with dimensions of the initial chamber of $170\mu \times 175\mu$ excluding the walls. The total length may vary considerably, since the second embryonic chamber tends to grow on a different plane to that of the initial chamber in many Lepidocyclines.

The first chamber of the spiral lies at one end of the septum between the two embryonic chambers, and is always larger than the chamber at the opposite end.

In the microspheric form (Pl. XL, Fig. 6, Text-Fig. 4) the embryonic spiral consists of a small spherical chamber followed by nine chambers enclosed in a thick wall, which continues outwards for a short distance and encloses a mass of chambers of varying shape and size. This arrangement is reminiscent of *Helicolepidina* but is undoubtedly different, whilst the remainder of the equatorial chambers also resemble *Helicolepidina* in their variation in size, shape, and their lack of arrangement, a fact which was noted for the megalospheric form in the original description.

In *transverse section* there are seen to be ± 6 layers of lateral chambers over the embryo, with an average measurement of 50μ horizontally and 22μ vertically, which are divided by walls 20μ thick. There are no pillars present, and the equatorial layer increases from 35μ at the centre to 85μ at the periphery.

In *tangential section* there are no pillars, and the lateral chambers are irregularly polygonal without any definite arrangement.

Rutten (15) describes this form as ? *Isolepidina*, but study of our specimens leads us to believe that this species is referable to the sub-genus *Polylepidina*, since the embryo consists of two large initial chambers followed by a spiral of smaller chambers.

Occurrence in Lobitos.—Well samples of the *Helicolepidina* Sandstone, together with *Discocyclina restinensis* and *Helicolepidina spiralis*.

Discocyclina peruviana (Cushman).

(Pl. XXXIX, Figs. 1, 2, 6, 8.)

1922. *Orthophragmina peruviana* Cushman (5), p. 138, pl. xxiv, fig. 3.
1924. *Discocyclina peruviana* (Cushman) Vaughan (20), p. 792.
1927. *Orthophragmina* (*Discocyclina*) *peruviana* Cushman, Berry (1), pp. 470–1.
1932. *Discocyclina peruviana* (Cushman), Wright Barker (25), p. 306.

Original Description.—" Test circular, consisting of two portions, the central raised, umbonate, occupying about one-third of the diameter of the test, surrounded by a thin flange-like portion of equal width ; surface coarsely papillate, both the centre and the peripheral portion almost equally so ; diameter about 6 mm."

The specimens obtained from the Terebratula beds at El Alto, in north-west Peru, belong to this species, as is shown by comparison with sections of the type material obtained from the Sedgwick Museum, Cambridge (C. 449–C. 454), and it is now possible to give a fuller description based on our sections and those in the Sedgwick Museum.

The test is circular, umbonate, with a thin, wide, undulating flange, and is papillate, the papillae being 110μ in diameter on the flange and 80μ on the dome. An average diameter for twenty specimens is 7·4 mm. with a maximum of 9 mm. and a minimum of 6 mm., and an average thickness through the dome for ten specimens is 0·95 mm., varying from 1·1 mm. to 0·6 mm. The dome occupies about 0·27 of the entire test, though in weathered specimens the periphery of the flange is destroyed, giving the appearance of a greater proportion of dome to flange.

Equatorial sections show that the embryo consists of a nearly circular initial chamber, half surrounded by a reniform second chamber. The average total length of the embryo is 245μ, varying from 220μ to 250μ, and the average longest diameter of the reniform second chamber is 226μ, varying from 185μ to 250μ. The average diameter of the initial cell is 123μ, varying from 110μ to 130μ, all these measurements including the embryonic wall, which is 8μ thick with little variation.

The chambers of the equatorial layer are rectangular, but vary considerably from being longer radially to longer tangentially, an average measurement for chambers at 1 mm. from the centre being 40μ radially and 29μ tangentially with a variation from 30μ to 55μ radially and 25μ to 35μ tangentially. Chambers at or near the periphery are somewhat larger, an average being 58μ radially and 26μ tangentially. These chambers are arranged in irregular annuli, separated by a wall 12μ thick, which shows clearly the inter-annular passages, and the septal walls do not alternate in successive annuli. (Pl. XXXIX, Fig. 2).

In the more perfect specimens the annuli are approximately circular, but in many specimens the inner annuli are seen to be cut tangentially by outer annuli, which may imply the repair of a broken flange.

Transverse sections show numerous pillars which terminate in papillae at the surface ranging from 90–100μ in diameter. The equatorial layer thickens from 20μ at the centre to 35μ at the periphery and is bounded by walls 10–15μ thick at the centre and 20μ thick at the periphery.

There are $\pm$ 14 layers of lateral chambers above the embryo which have an average measurement of 60μ horizontally and 18μ vertically. The variation in size of these lateral chambers is considerable, being from 90μ × 18μ to 30μ × 10μ for those on the dome, and the layers are separated by walls averaging 20μ thick.

Tangential sections show that the lateral chambers are irregularly polygonal in outline and are approximately 50–90μ × 50–90μ with dividing walls 5–7μ thick. The pillars are somewhat polygonal in outline with a diameter of from 90μ–145μ, and are 90–125μ apart.

Willard Berry (1) describes a microspheric form of *Discocyclina peruviana* (Cushman), which has a smaller test than the average megalospheric form and a slightly larger embryonic apparatus. This suggests that he was dealing with a young megalospheric specimen and not the microspheric form, which should possess a larger test and a much smaller embryonic apparatus.

	Discocyclina peruviana (Cushman). Type Material Wright-Barker (25).	*Discocyclina peruviana* (Cushman). Terebratula Beds.	*Discocyclina restinensis* sp. nov.	*Discocyclina peruviana* (Cushman). B. form Berry (1).
Diameter . .	6 mm.	7·4 mm.	5 mm.	2 mm.
Thickness . .	1·5–2·0 mm.	0·6–1·1 mm.	0·69–0·98 mm.	—
Diameter. Initial Chamber .	105μ	110–30μ	125–70μ	168μ
Embryo length .	—	220–50μ	215–75μ	—
Embryo width .	245μ	185–250μ	240–310μ	252μ
Median Layer Centre .	—	20μ	18μ	—
Median Layer Edge of Dome	—	28μ	22μ	—
Median Layer Periphery .	—	35μ	—	—

Lepidocyclina (*Lepidocyclina*) *peruviana* (Cushman). (Pl. XLI, Figs. 1–4; Pl. XLII, Figs. 2, 3, 5–7.)

1922. *Lepidocyclina* (*Nephrolepidina*) *peruviana* Cushman in Bosworth (4, p. 138).
1922. *Lepidocyclina antillea* Cushman (5), non Cushman (6).
1924. *Lepidocyclina peruviana* T. Wayland Vaughan (20, p. 797, footnote).
1928. *Lepidocyclina peruviana* Nuttall (13, p. 104).
1928. *Lepidocyclina* (*Isolepidina*) *r. douvillei* Lisson var. *armata* Rutten (15, p. 944, fig. 24 *l–m*, pl. ii, 27–8).
1932. *Lepidocyclina peruviana*, v. der Vlerk (23, p. 105).

Cushman's original description of *Lepidocyclina peruviana* (5, p. 138) is as follows :—

"Test small, circular, biconvex, highest in the central region, thence gradually sloping to the periphery, where there is a thin flange-like portion merging gradually into the central mass ; centre with a few well-developed pillars, seen on the surface as rounded papillae ; peripheral portion with a few small pillars, wanting near the edge ; horizontal sections show the equatorial chambers diamond shape, as is usual in this subgenus. Diameter, 3 mm. or less."

To this we add a description of the internal structure based on thirty-two of our sections, seven sections of the type material of *Lepidocyclina peruviana* and five sections of the type material of *Lepidocyclina* "*antillea*" from the Lobitos formation of north-west Peru.

Equatorial sections show that an average total length of the embryonic apparatus, which is Lepidocycline in type, is 276μ, varying from 204μ to 340μ, whilst an average greatest width is 187μ, varying from 148μ to 237μ, these measurements including the embryonic walls.

The septum between the two embryonic chambers averages 12μ thick and may be straight or slightly curved, whilst the embryonic walls vary from 18μ to 22μ thick. In some sections the walls at the ends of the longest diameter of the embryonic apparatus may be as much as 35μ thick. Equatorial chambers vary in shape from arcuate to ogival and in size from 22–40μ radially by 22–40μ tangentially, being usually slightly greater tangentially.

Transverse sections show that the equatorial layer expands from about 37μ at the centre to 110μ at the periphery and has walls 18μ thick dividing it from the lateral chambers. There are ± 9 layers of lateral chambers which are 100–10μ horizontally and 20–30μ vertically near the surface in the centre. Pillars are present, which are 90–100μ thick at the surface, where they end in papillae.

Tangential sections show that the lateral chambers are subcircular and are arranged in an irregular spiral. The pillars are polygonal and vary from 90μ to 140μ thick.

Discussion.—It became apparent to us, while studying sections of Bosworth's material of *Lepidocyclina peruviana* Cushman and *Lepidocyclina antillae* Cushman from the Lobitos formation (5, p. 137), that in spite of certain differences the two are, in fact, one species. This species seems to agree with *Lepidocyclina r. douvillei* var. *armata* Rutten, differing from *Lepidocyclina r. douvillei* Lisson in the possession of pillars and a much smaller embryonic apparatus. *Lepidocyclina r. douvillei*, as described by van der Vlerk (23, p. 105, pl. xi, fig. 1–3), possesses an embryonic apparatus varying in diameter from 410μ–530μ, whereas measurements from Rutten's figures of var. *armata* give the diameter as between 260μ and 300μ.

Vaughan (20, p. 797) and Nuttall (13, p. 104) say that *Lepidocyclina peruviana* is a synonym of *Lepidocyclina r. douvillei*, an opinion with which van der Vlerk disagrees (23, p. 105), pointing out that *Lepidocyclina peruviana* differs in the possession of a flange and well-developed pillars.

We suggest that *Lepidocyclina* (*Nephrolepidina*) *peruviana* Cushman, and the species from the Lobitos formation referred to *Lepidocyclina* (*Polylepidina*) *antillae* Cushman, are synonymous, and, furthermore, are the same as *Lepidocyclina r. douvillei* var. *armata* Rutten, since they possess embryonic and median chambers in the same range of measurements and show a marked similarity in other respects (Table, p. 539). These must be assigned to the subgenus *Lepidocyclina*, since the embryonic apparatus consists of two subequal chambers divided by a straight or slightly curved septum and surrounded by a thick wall.

Certain forms show a well-developed flange and others a robustly lenticular cross-section, but, taken in conjunction with the close similarity in internal structure, we believe this to be of only varietal significance.

Material.—Large numbers of Lepidocyclina were collected from the Yapato Grit, the Organos Grit, and the Cardo Grit. The first two of these grits are considered as being contemporaneous, the latter as being of slightly later age. In the field the Cardo Grit is seen to be separated from the Yapato Grit by a series of alternating shales and sands, but these would appear to have been rapidly deposited. Careful study of thin sections convinced us that we were dealing with one species from all three formations, though variation was so considerable that no two individuals were identical.

Occurrence near Lobitos.—Yapato Grits, Cardo Grits, Organos Grits.

Lepidocyclina (*Lepidocyclina*) sp. aff. *sherwoodensis* Vaughan.
(Plate XL, Fig. 1; Plate XLI, Fig. 6; Plate XLII, Fig. 4.)

Reference to *L. sherwoodensis* is :—

1928. *Lepidocyclina* (*Lepidocyclina*) *sherwoodensis* Vaughan (20*a*, p. 287, pl. xlviii, figs. 4–8).

Numerous specimens were collected, but the majority of these are badly weathered and often prove to be recrystallized when sectioned. A microspheric form is seen to be present in thin section, but no distinction can be made between the two, externally, in the material.

The test is circular in outline, domed with a small flange, and the surface appears somewhat pustulate. Some specimens appear to be lenticular, but it is probable that the outer chambers of the equatorial layer, which form the thin flange, have been weathered off. An average diameter of twenty specimens is 1·95 mm., and an average thickness through the centre for fifteen specimens is 0·81 mm., varying from 0·7 to 0·9 mm.

Horizontal sections show two large initial chambers surrounded by a mass of smaller chambers, which, however, are considerably larger than the later equatorial chambers, and which gives the resemblance of the "mulberry mass" arrangement described by Vaughan in *Polylepidina* (21).

An average total length of the first two chambers is 254μ (222μ–307μ) and an average greatest width is 177μ (156μ–204μ), including the embryonic walls which are 18μ thick. One section has a larger embryo which measures 381μ in total length and 233μ greatest width. The septum between the two chambers is straight or slightly curved and about 10μ thick.

The median chambers at about 0·5 mm. from the centre average 35μ radially and 34μ tangentially, and are rhomboid.

Transverse sections show that the equatorial layer expands as it approaches the periphery from 37μ near the centre to 160μ at the periphery. There are about nine layers of lateral chamber over the centre. In the section figured (Pl. XLII, Fig. 4) the length of the embryonic apparatus is 250μ and the height 150μ.

Pillars are irregularly formed and may measure as much as 110μ in thickness at the surface, though usually they are only about 75μ.

Tangential sections show that the lateral chambers are subcircular in outline except near the centre where they elongate, and have no definite arrangement. Pillars are present, but are irregular in formation.

Comparison.—This species is distinct from other Peruvian *Lepidocyclines* described in this paper as is shown by tangential sections (Pl. XLI, Fig. 6), and in horizontal section the equatorial chambers are rhomboid instead of open arcuate to ogival (Pl. XL, Fig. 1). The species most closely related to this form is *Lepidocyclina sherwoodensis* Vaughan, the only marked difference being the absence of the ragged appearance in transverse section which was considered characteristic of the latter species. This difference, however, may be due to the state of preservation.

Occurrence in Lobitos.—Abundant in the Purple Sandstones and Shales.

Lepidocyclina (*Lepidocyclina*) sp. aff. *Kugleri* van der Vlerk.
(Plate XL, Fig. 2; Plate XLI, Fig. 5; Plate XLII, Fig. 1.)

Reference to *L. Kugleri* is :—

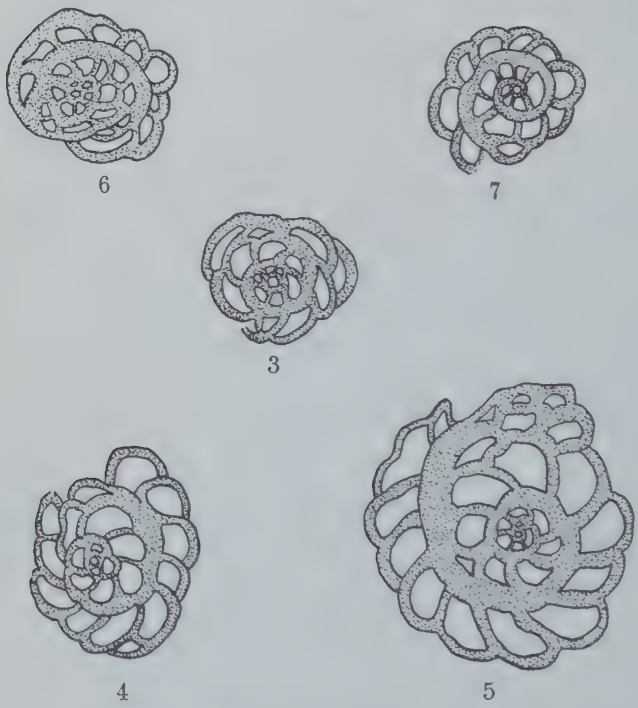
1932. *Lepidocyclina* (*Lepidocyclina*) *Kugleri* v. der Vlerk (23).

A number of specimens were collected which seem to agree in shape and structure with *Lepidocyclina* (*Lepidocyclina*) *Kugleri* van der Vlerk from the Menegrande Series (Upper Eocene) of Falcon, Venezuela. The embryonic apparatus in Peruvian specimens is considerably smaller, varying in length from 260μ to 295μ, as compared with 350μ to 400μ, but, taken in conjunction with the close similarity in other measurements, we feel that this discrepancy may probably be neglected. Though we do not intend definitely

	Diameter.	Thickness.	Length of Embryo.	Median Layer Centre.	Median Layer Periphery.	Layers of Lateral Chambers.	Thickness of columns at surface.
Lepidocyclina peruviana Cushman. Type Material	—	—	265–295μ	38μ	95μ	± 9	90μ
Lepidocyclina "*antillea*". Bosworth's collection .	—	—	222–240μ	45μ	100μ	10	90–130μ
Lepidocyclina peruviana. Cardo Grits . . .	Av. 2·3 mm.	Av. 0·94 mm.	204–307μ	37μ	110μ	± 9	92μ
Lepidocyclina peruviana. Organos Grits . .	Av. 2·9 mm.	Av. 1·0 mm.	207–307μ	37μ	110μ	± 9	92–110μ
Lepidocyclina peruviana. Yapato Grits . . .	Av. 2·5 mm.	Av. 0·8 mm.	248–315μ	37μ	95μ	+ 6	—
Lepidocyclina r. douvillei Lisson var. *armata* Rutten	1·5–2·5 mm.	0·7–1·0 mm.	266–297μ	—	—	—	—
Lepidocyclina r. douvillei Lisson	2·7–3·2 mm.	± 1·3 mm.	410–530μ	60μ	130μ	± 9	None.
Lepidocyclina sp. aff. *sherwoodensis* Vaughan . .	Av. 1·95 mm.	Av. 0·81 mm.	222–381μ	37μ	160μ	± 9	75–110μ
Lepidocyclina sherwoodensis Vaughan . . .	1·5–2·5 mm.	About 0·5 mm.	250–400μ	—	—	—	70–150μ
Lepidocyclina sp. aff. *Kugleri* v. der Vlerk. Upper Purple Sst.	Av. 2·9 mm.	Av. 1·27 mm.	260–295μ	45μ	137μ	12	165μ dome. 65μ flange.
Lepidocyclina Kugleri v. der Vlerk	2·7–4·8 mm.	—	350–400μ	—	—	8–10	145μ on dome.
Lepidocyclina trinitatis H. Douvillé . . .	1·6–3·5 mm.	1·0–1·5 mm.	310–480μ	50μ	100μ	± 9	145μ on dome. 60μ flange.

to class this form as *L. Kugleri*, we have found that the dimensions of the embryo in many of our specimens of *Lepidocyclina* show a considerable range, specific identity depending rather on a general aggregate of features than on the similarity of any one.

Occurrence in Lobitos.—Upper Purple Sandstone.



Microspheric Forms.

Fig.
3.—*Lepidocyclina* sp. aff. *sherwoodensis* Vaughan. × 120. B.M. No. P. 30294.
4.—*Lepidocyclina richayalensis* Rutten. × 115. B.M. No. P. 30243.
5.—*Helicolepidina spiralis* Tobler. × 126. B.M. No. P. 30248.
6.—*Lepidocyclina* "*antillae*" from Bosworth's collection. × 120. Sedg. Mus. C. 417.
7.—*Lepidocyclina peruviana* from Cardo Grits. × 130. B.M. No. P. 30278.

Stratigraphical Results.

Considerable work has been done on the distribution of the Orbitoidinae by H. Douvillé (9, 10), I. M. van der Vlerk (22, 23), T. W. Vaughan (19, 20), and others, and has been summarized by W. à Wengen (24).

Recent work on the foraminiferal faunas of Ecuador and Peru, in an attempt to fill some of the gap in the Southern part of the

New World, has only emphasized the paucity of our knowledge as to what horizons the various subgenera of *Lepidocyclina* and *Discocyclina* characterize in that part of the world.

In Venezuela, van der Vlerk has shown that *Lepidocyclina* (*Lepidocyclina*) goes back to the earliest orbitoid bearing beds, as does *Discocyclina*. W. à Wengen, on the other hand, in his phylogenetic chart of the Orbitoidinae (24, p. 457) shows the range of *Lepidocyclina* as being considerably later than that of *Discocyclina* in North America, the only period of overlap of the two genera being the Jackson-Ocala formation. In Ecuador, *Lepidocyclina* has not been found in association with *Discocyclina s.s.*, though *Asterocyclina* and *Actinocyclina* appear to bridge the intervening gap.

In Peru, there is still so much confusion with regard to the sequence of greatly disturbed beds that it is difficult to draw any definite conclusions as to the distribution of the Orbitoids. Here, as in Ecuador, Venezuela, and Trinidad, we have a bed containing *Helicolepidina*, *Discocyclina*, and *Polylepidina*. Below this *Discocyclina s.s.* predominates, whilst considerably higher in the succession we have the absence of *Discocyclina* and the predominance of *Lepidocyclina*.

It is suggested that *Lepidocyclina*, which, in Peru, shows many similarities to *Polylepidina*, begins later in this region than in Central America, and that *Discocyclina* dies out earlier. It also appears that *Helicolepidina* has a more extended vertical range than has hitherto been believed, occurring in such widely separated beds as the Helicolepidina Sand, the Convento Beds, and the Organos Grits.

LIST OF LITERATURE CITED.

(1) Berry, Willard. "The Microspheric form of *Orthophragmina* (*Discocyclina*) *peruviana* Cushman," *Eclog. geol. Helvet.*, Bd. xx, 1927, 470–1.

(2) —— "*Asterodiscocyclina*, a new subgenus of *Orthophragmina*," *Eclog. Geol. Helvet.*, xxi, 1928, 405–7, pl. xxxiii.

(3) —— "The larger Foraminifera of the Talara Shale of North-western Peru," *Journ. Wash. Acad. Sciences*, xxii, 1932, 1–9.

(4) Bosworth, T. O. *The Geology and Palaeontology of North-West Peru.* London, 1922.

(5) Cushman, J. A. "Foraminifera from the Eocene deposits of Peru," in Bosworth, see above, 1922.

(6) —— "Fossil Foraminifera from the West Indies," Carnegie Inst. Washington, Publication No. 291, 1919, 23–71.

(7) —— "The American species of *Orthophragmina* and *Lepidocyclina*," *U.S. Geol. Survey, Professional Paper* 125, 1920, 39–105, pls. vii–xxxv.

(8) Douvillé, H. "Quelques observations sur le sous-genre *Helicolepidina*," *Eclog. geol. Helvet.*, xvii, 1923.

(9) —— "Les Orbitoids et leur évolution en Amerique," *Bull. Soc. géol. France* [4], xxii, 1923, 369–76.

(10) —— "Révision des Lépidocyclines," *Mém. Soc. géol. de France*, Nouvelle Série, i, Mém. 2, 1924–5.

(11) Hodson, H. K. "Foraminifera from Venezuela and Trinidad," *Bulletin of American Palaeontology*, xii, No. 47.

(12) Lisson, C. I. "Contribution al estudio de algunos foraminifera terciarios provenientes de la region del Norte del Perú," *Arch. Asoc. Peruana, Prog. Ciencia*, i, Fax. i, 52–5.

(13) NUTTALL, W. L. F. "Tertiary Foraminifera from the Naparina Region of Trinidad," *Quart. Journ. Geol. Soc.*, lxxxiv, 1928, 57–116.
(14) OLSSON and IDDINGS. "Geology of North-Western Peru," *Bull. Amer. Soc. Petrol. Geol.*, xii, 1928, 1–39.
(15) RUTTEN, L. "On Tertiary Rocks and Foraminifera from North-Western Peru," *Kon. Akad. van Wetensch.*, Proc. 31, 1928, 931–46.
(16) TOBLER, A. "Die Jackstonstufe (Preabonien) in Venezuela und Trinidad," *Eclog. geol. Helvet.*, xvii, 1922, 342–6.
(17) —— "Helicolepidina, ein neues Subgenus von Lepidocyclina," *Eclog. geol. Helvet.*, xviii, 1922, 379–84.
(18) —— "Neue Funde von Grossforaminiferen in der Nordperuanischen Kustenregion," *Eclog. geol. Helvet.*, xx, 1927, 415–22.
(19) VAUGHAN, T. W. "Studies of the larger Tertiary Foraminifera from tropical and subtropical America," *Proc. Nat. Acad. Sciences*, ix, 1923, 253–7.
(20) —— "American and European Tertiary Larger Foraminifera," *Bull. Geol. Soc. Amer.*, xxxv, 1924, 785–822.
(20*a*) —— "Species of large Arenaceous and Orbitoidal Foraminifera from the Tertiary Deposits of Jamaica," *Journ. Palaeontology*, i, 1928, 277–98, pls. xliii–l.
(21) —— "Studies of Orbitoidal Foraminifera: the subgenus *Polylepidina* of *Lepidocyclina*, and *Orbitocyclina*, a new genus," *Proc. Nat. Acad. Sciences*, xv, 1929, 280–95.
(22) VLERK, I. M. van der. "The genus Lepidocyclina in the Far East," *Eclog. geol. Helvet.*, xxi, 1928, 182–211, pls. vi–xxiii.
(23) —— and GORTER, N. E. "Larger Foraminifera from Central Falcon (Venezuela)," *Ludsche Geol. Mededeelingen*, Dl. iv, Afl. 2, 1932, 95–122.
(24) WENGEN, W. à. "Phylogenetic considerations of the Nummulinidae," *Proc. of the Fourth Dutch East Indian Congress of Natural Science*, Weltevreden (Java), 1926, 448–66.
(25) WRIGHT BARKER, R. "Larger Foraminifera from the Eocene of Santa Elena Peninsula," GEOL. MAG., LXIX, 1932, 302–10.

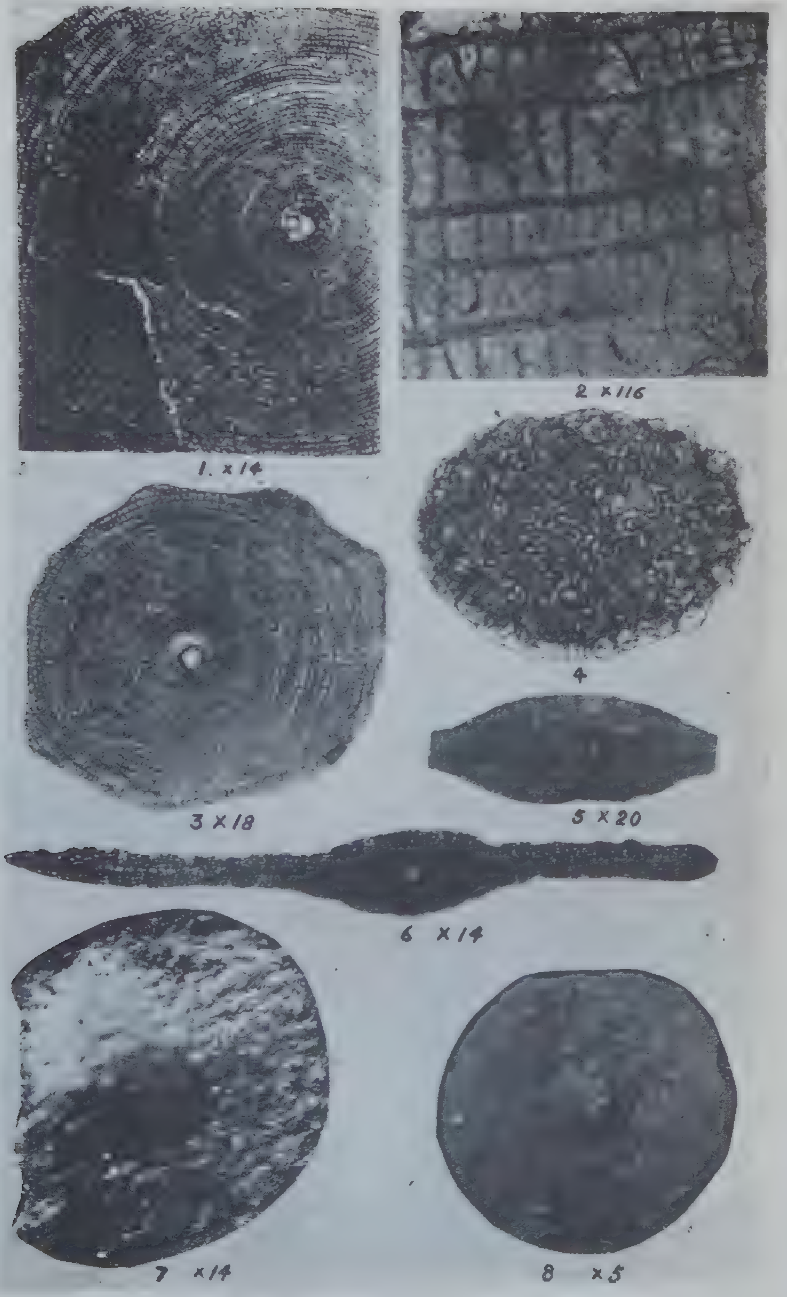
EXPLANATION OF PLATES XXXIX–XLII.

PLATE XXXIX.

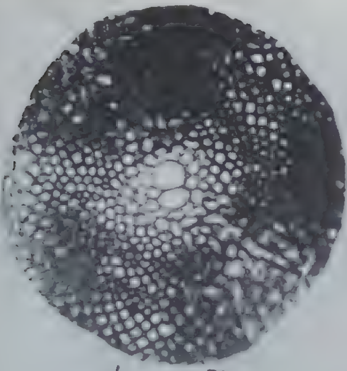
FIGS.
1.—*Discocyclina peruviana* (Cushman). Horizontal section. B.M. No. P. 30239.
2.—*Discocyclina peruviana* (Cushman). Horizontal section showing inter-annular and annular stolon passages. B.M. No. P. 30231.
3.—*Discocyclina restinensis* sp. nov. Horizontal section. B.M. No. P. 30219.
4.—*Discocyclina restinensis* sp. nov. Tangential section. B.M. No. P. 30216.
5.—*Discocyclina restinensis* sp. nov. Transverse section. B.M. No. P. 30218.
6.—*Discocyclina peruviana* (Cushman). Transverse section. B.M. No. P. 30233.
7.—*Discocyclina restinensis* sp. nov. External. B.M. No. P. 30215.
8.—*Discocyclina peruviana* (Cushman). External. B.M. No. P. 30230.

PLATE XL.

1.—*Lepidocyclina* (*Lepidocyclina*) sp. aff. *sherwoodensis* Vaughan. Horizontal section. B.M. No. P. 30286.
2.—*Lepidocyclina* (*Lepidocyclina*) sp. aff. *Kugleri* v. der Vlerk. Horizontal section. B.M. No. P. 30298.
3–4.—*Helicolepidina spiralis* Tobler. Horizontal sections. Fig. 3, Microspheric form. B.M. No. P. 30248. Fig. 4, Megalospheric form. B.M. No. P. 30247.
5–6.—*Lepidocyclina* (*Polylepidina*) *vichayalensis* Rutten. Horizontal sections. Fig. 5, Megalospheric form. B.M. No. P. 30242. Fig. 6, Microspheric form. B.M. No. P. 30244.



Discocyclina.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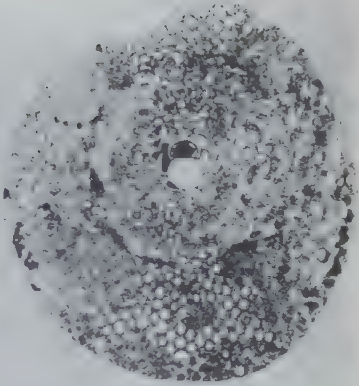
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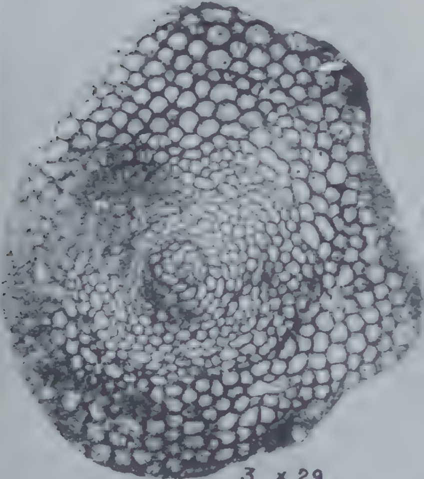
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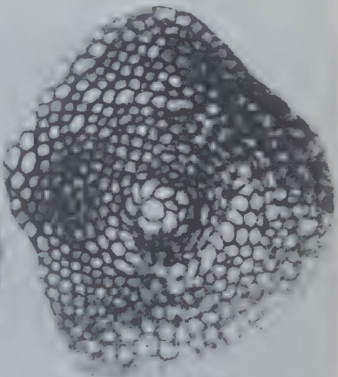
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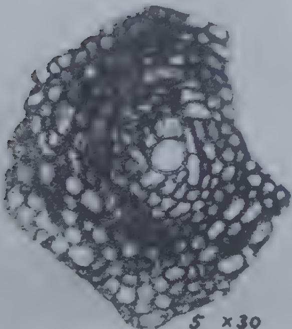
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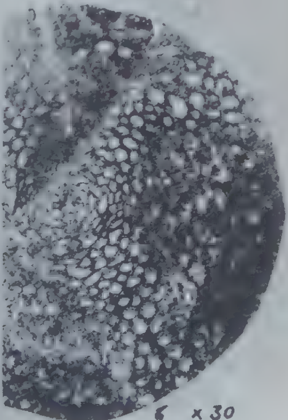
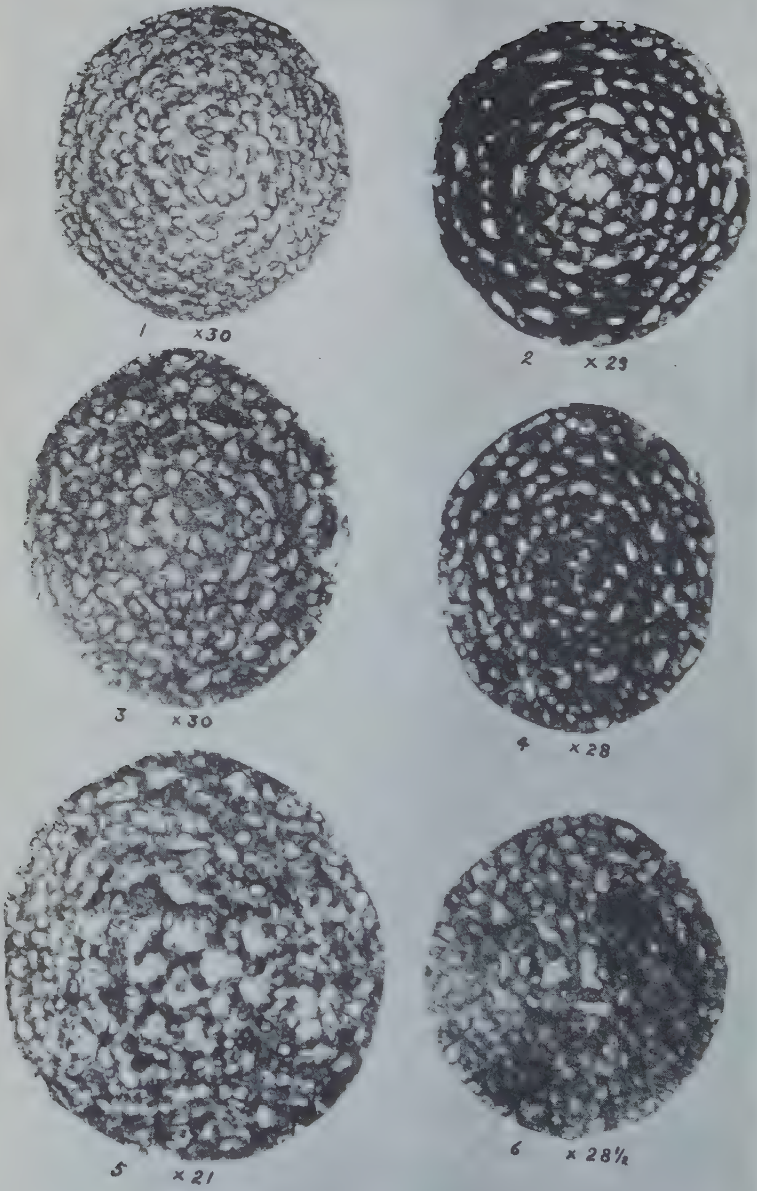
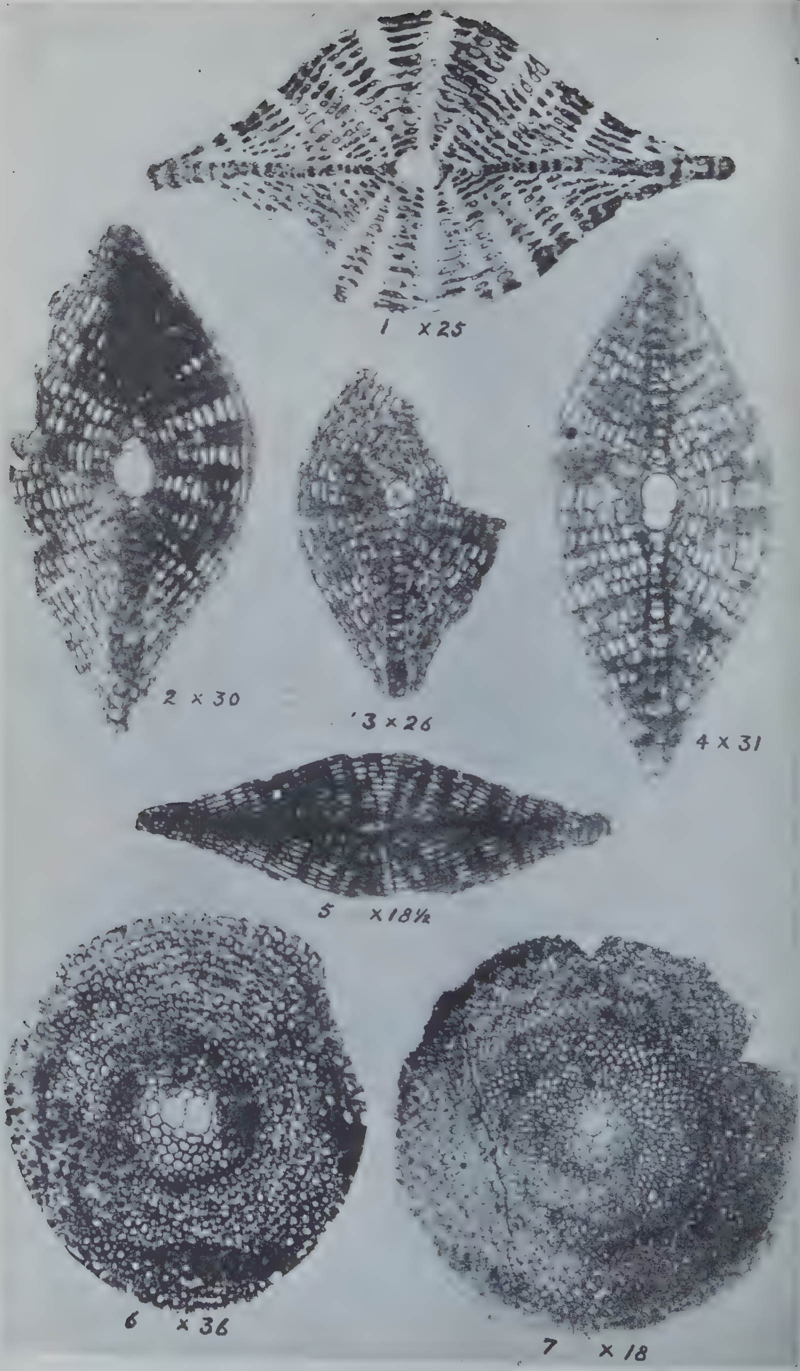

6 ×30

LEPIDOCYCLINA AND HELICOLEPIDINA.



Lepidocyclina (Tangential Section).



LEPIDOCYCLINA.

PLATE XLI.

FIGS. *Tangential Sections.*

1.—*Lepidocyclina* (*Lepidocyclina*) *peruviana* Cushman. Specimen from the Cardo grits. B.M. No. P. 30276.
2.—*L. peruviana.* Type material from Bosworth's collection. Sedg. Mus. C. 436.
3.—*L. peruviana.* Specimen from the Organos grits. B.M. No. P. 30255.
4.—*L.* "*antillea*" Cushman. Specimen from Bosworth's collection. Sedg. Mus. C. 420.
5.—*Lepidocyclina* (*Lepidocyclina*) sp. aff. *Kugleri* v. der Vlerk. Specimen from Upper Purple Sandstone. B.M. No. P. 30300.
6.—*Lepidocyclina* sp. aff. *sherwoodensis* Vaughan. Specimen from the Purple Sandstones and Shales. B.M. No. P. 30289.

PLATE XLII.

1.—*Lepidocyclina* (*Lepidocyclina*) sp. aff. *Kugleri* v. der Vlerk. Transverse section. B.M. No. P. 30299.
2.—*Lepidocyclina* "*antillea*" Cushman. Transverse section from Bosworth's collection. Sedg. Mus. C. 421.
3.—*Lepidocyclina peruviana* Cushman. Transverse section of type material from Bosworth's collection. Sedg. Mus. C. 432.
4.—*Lepidocyclina* sp. aff. *sherwoodensis* Vaughan. Transverse section. B.M. No. P. 30287.
5.—*Lepidocyclina peruviana.* Transverse section from the Organos grits. B.M. No. P. 30254.
6.—*Lepidocyclina peruviana.* Horizontal section of type material from Bosworth's collection. Sedg. Mus. C. 434.
7.—*Lepidocyclina peruviana.* Horizontal section from the Organos grits. B.M. No. P. 30258.

The Origin of Igneous Rocks.

By ARTHUR HOLMES, The University, Durham.

THE CRUST AND THE SUBSTRATUM.
THE GENESIS OF MAGMAS BY REFUSION.
THE ORIGIN OF GRANITE MAGMA IN KRATOGENIC REGIONS.
THE ORIGIN AND BASIFICATION OF GRANITE IN OROGENIC BELTS.
THE ACIDIFICATION OF BASALTIC MAGMAS.
A NEW KEY TO PETROGENESIS.
THE ORIGIN OF PERIDOTITES.
THE ORIGIN OF ALKALI ROCKS.
CONCLUSIONS.

THE CRUST AND THE SUBSTRATUM.

THE leading problems presented by igneous rocks are :—
(*a*) the nature and sources of the primary magmas ;
(*b*) the mechanics of magmatic intrusion and emplacement ; and
(*c*) the processes which have brought about the manifold diversity of igneous rock-types.

These genetic problems are closely related, and all efforts to solve them lead back by one route or another to the composite problem of the composition, arrangement, and thermodynamics of the outer shells of the earth. Present interpretations of composition and arrangement can be briefly summarized thus :—

Seismic evidence suggests the following downward succession for certain continental regions :—

Layer.	*Velocity in Km./Sec.*	*Thickness.*
1. Sedimentary	$P_s = 2\cdot2–5\cdot0$	Widely variable.
2. Upper or " Granitic "	$P_g = 5\cdot4–5\cdot6$	About 10–15 km.
3. Upper Intermediate	$P^* = 6\cdot0–6\cdot5$	About 15–20 km.
4. Lower Intermediate	$P_Q = 6\cdot8–7\cdot1$	
5. Lower	$P = 7\cdot8 +$	Perhaps extending to core.

The composition of layer 3 is doubtful, but Gutenberg has recently shown (1932, p. 41) that in North Germany this layer approaches the surface and takes the place of the granitic layer ; hence it becomes probable that, there at least, layer 3 may be a deeply eroded Pre-Cambrian basement made up of rocks of granitic and basaltic composition in roughly equal proportions in the upper part, passing downwards into more dominantly basaltic material. Consistent with this interpretation is the evidence provided by the xenolithic contents of kimberlite pipes in South Africa (Wagner, 1928). It is almost certain that layer 4 is composed of basaltic material, and that it represents the lower part of the world-wide " basaltic layer " now widely accepted as the source of plateau and oceanic basalts and related intrusions. The Lower layer appears at a depth of 30–40 km., and its composition is commonly regarded as akin to that of peridotites or stony meteorites, though Daly includes at least the upper part of it in his " basaltic layer "—crystalline above and glassy below. My own view is that the Lower layer is likely to be peridotite (perhaps with eclogite, locally) passing down into an ultrabasic and still glassy substratum. Gutenberg and Richter conclude a recent paper with the statement : " It is not impossible that at some depth between 40 and 80 kilometres there is a transition from the crystalline to the glassy state " (1932, p. 222).

Layers 4 and 5 seem to be of world-wide occurrence, whereas 2 and probably also the upper part of 3 appear to be absent from a considerable part of the floor of the inner Pacific and to be thin and patchy in the Atlantic floor. It is possible that the basaltic material of 3 is in the amphibolite facies (providing a potential source for olivine-free basaltic rocks), while 4 may be in the basic granulite facies (providing a potential source for undersaturated basaltic rocks).

There is a growing belief in the existence of a glassy substratum which is the source of magmas or of a considerable part of the heat necessary to generate magmas from the crystalline materials of the overlying layers. If the substratum is crystalline and essentially non-radioactive, as assumed by Jeffreys (1929), then the copious production of basaltic magma represented by plateau lavas remains incomprehensible. The crust down to 60 km. or so must be much more strongly radioactive than the substratum. Any local increase in the thickness of this "radioactive layer" (e.g. in belts of geosynclinal sedimentation and subsequent mountain building) must inevitably bring about a rise of temperature in depth, thus favouring the production of magma. Plateau basalts, however, have commonly ascended in kratogenic regions like the Deccan, where the crust had already been deeply denuded; that is to say, in regions where the radioactive layer had been thinned. The source of the excess heat necessary to generate magmas in such a geological setting cannot therefore be ascribed to crustal radioactivity, but must be looked for in the substratum.

THE GENESIS OF MAGMAS BY REFUSION.

If the substratum is feebly radioactive, then it must be periodically or permanently glassy, and whenever mechanical or thermal conditions permit this potential magma to ascend towards the surface, heat from the depths will be transferred to higher levels in the crust: whence refusion will occur wherever the temperature rises to the minimum of the fusion-range of the materials being heated up (Holmes, 1926, p. 315; Poole, 1930; Eskola, 1932, p. 472). Suppose that for any of numerous possible reasons the primary peridotite magma of the substratum locally acquires a temperature above that of the minimum fusion point of its own roof: a wave of magma will then begin to ascend through the layer of crystalline peridotite, and in certain cases the basaltic layer will be reached. Partial fusion of the latter will already have begun as soon as the isogeotherms rising in advance of the ultrabasic magma reach the minimum fusion point of basaltic materials. Once the two magmas come into contact, relatively rapid production of basaltic magma is to be expected. As this magma works its way up, it may in turn reach the granitic rocks of the Upper Intermediate or Upper layers —rocks which will already have begun to fuse differentially before the achievement of actual contact. It has been conclusively shown by Greig, Shepherd, and Merwin (1929) that even under laboratory conditions granite melts at considerably lower temperatures than basalt, the difference being more than 200° C. Thus, where basaltic magma comes within close range of rocks containing the constituents of quartz and alkali felspars, partial refusion will be inevitable so long as the environment remains one of rising temperatures. Where the magmatic cauldron rising in the crust is of sufficient size, the complex processes of refusion, reaction, stoping, and assimilation (*anatexis* of Sederholm, 1907, p. 102) will carry the magma towards the surface until cooling through the roof and walls turns the environment into one of falling temperatures. Differentiation by crystallization will have begun to operate before assimilation has ceased, and will continue throughout the period of consolidation. Smaller bodies of magma may begin to cool and crystallize at any depth in the crust, while the largest may conceivably work through to the surface itself, though in general they will ascend into a volcanic pile of their own upbuilding and die out within its heart. At any stage in the development, fissures may tap the rising magma or magmas, and the composition of the resulting rapidly chilled lava flows (or sills and dykes) will depend on that of the magma which gains access to the fissures. A magma like that of basalt may enter a fissure after a more viscous one, say of granitic composition, and in virtue of its superior mobility outstrip the latter in the ascent towards the surface.

Igneous activity is thus regarded as a consequence of crustal refusion brought about by (i) radioactivity, and (ii) the ascent of heat from the glassy substratum. Our hypothesis suggests that at least three kinds of "parent" magma—peridotitic, basaltic, and granitic—are likely to be generated. This "three magma" hypothesis is relatively new, for although I first suggested it in 1915 (p. 73), it is only during the last few years that I have begun to develop it in the light of specific petrological evidence.

THE ORIGIN OF GRANITE MAGMA IN KRATOGENIC REGIONS.

As early as 1851, Bunsen advocated a double parentage to account for the association of acid and basic rocks in Iceland, but until recently Bunsen's ideas have been neglected, and valiant attempts have been made to derive all igneous rocks from a single basaltic source, the actual diversity of types being ascribed to various processes of differentiation, with or without assimilation of country rock (Daly, 1914; Niggli, 1923; Bowen, 1928). It is desirable to consider how far these attempts have been successful.

It is now generally agreed that differentiation from olivine-basalt magmas is competent to account for series such as melanocratic olivine-basalt—olivine-basalt—trachybasalt—trachyte, and their plutonic equivalents. Such associations are found in oceanic volcanoes (Hawaii, Réunion, Jan Mayen) and in the central complexes of kratogenic continental regions (Thulean, Deccan, and Oregonian provinces). Quite exceptionally, quartz-trachyte or soda-rhyolite occur (Marquesas, Ascension), but far more commonly felspathoidal types are present.

The most abundant type of plateau basalt, however, is feebly oversaturated. When it crystallizes in minor intrusions as quartz-dolerite, it commonly generates a final residual liquid of granitic composition represented by interstitial micropegmatite. Sometimes even olivine-dolerite may have a mesostasis of this composition (Säppi, Finland: Eskola, 1932, p. 461). So far as we know, such rocks are confined to continental regions and they are frequently associated with granite, granophyre, felsite, pitchstone, or rhyolite (Thulean province, Karroo basins of Africa, Bushveld, Sudbury, etc.). It has therefore been widely inferred that such acid rocks can be ascribed to differentiation from basaltic magma, the residual liquid being separated in bulk from the crystalline phases by (i) passive sinking of the latter, or (ii) active squeezing out of the former. Various objections to this view have been recently published, notably by Fenner (1931) and Krokström (1932). I have also presented a number of reasons for believing that this hypothesis of the origin of granite cannot be generally applicable and is in any case unnecessary (Holmes, 1931). They include :—

(*a*) The absence of rhyolites and their equivalents from the basaltic volcanoes of the inner Pacific.

If basaltic magma fails to produce acid rocks (other than rare quartz-trachytes) where the granitic layer is missing, how can it do so in continental areas? Only by supplying heat to the granitic materials which are already available in these areas for refusion.

(*b*) The evidence that the cone-sheets of the British Tertiary province spring from foci at a depth of about three miles, with the implication that the underlying magma reservoir must have penetrated far into the granitic part of the crust.

If the granitic material was not fused we are at a loss to account for its apparent disappearance.

(*c*) The theoretical deduction that in a cupola-shaped reservoir of basaltic magma slow cooling combined with convective stirring prevents the accumulation of the free silica liberated by the early crystallization of "excess" olivine.

Under these circumstances, differentiation may proceed towards a trachytic residuum, but it can hardly do so along an andesite-dacite-rhyolite line of descent.

(*d*) The striking paucity of evidence from kratogenic regions of the development of magmas of intermediate (andesitic) composition such as would be expected to occupy the gap in the liquid line of descent from basalt to rhyolite.

Peacock has recently stressed this difficulty with a wealth of cogent illustration from Iceland (unpublished thesis).

(*e*) The widespread evidence from which the co-existence of acid and basic magmas is inferred.

It cannot be denied that in appropriate circumstances some micropegmatite may be produced from basaltic magma, but the different lines of circumstantial evidence summarized above converge to the conclusion that such magma is not normally a source of granite in kratogenic areas; nor can it be regarded as a potent source of andesites and dacites in such areas. Where dioritic rocks occur they generally have the characters of hybrids, the parent magma being granitic.

THE ORIGIN AND BASIFICATION OF GRANITE IN OROGENIC BELTS.

It seems reasonable, therefore, to advance a step further and examine the inference that in orogenic belts it is unlikely that the diorite—granodiorite—granite and andesite—dacite—rhyolite suites originated by differentiation from basaltic magma. Smooth variation diagrams covering this range and linking them with basalt or gabbro (Katmai, Lassen Peak, etc.) may be consistent with differentiation, but they do not prove it. Mixtures of basaltic and granitic materials would give similar nearly straight-line curves.

If granite magma can be produced by refusion in kratogenic areas, then in the thickened zones of orogenic belts its generation is likely to be in far greater amounts. Eskola (1932) has presented much cogent evidence supporting the hypothesis of refusion during orogenesis. As granite appears during and immediately after orogenesis we have a direct proof that the refusion was not wholly accomplished by radioactive heating in the sialic roots. Such heating would be competent to bring about refusion on a vast scale, but only after the lapse of a hundred million years or more. The absence of a time interval indicates that here, as in the kratogenic areas, heat from the substratum must also be involved. This conclusion is consistent with (i) the fact that in the pre-orogenic stage contemporaneous vulcanism often accompanies the infilling of a geosyncline, and with (ii) the rule that in orogenic igneous complexes the common order of plutonic intrusion is from ultrabasic though basic to acid.

Field evidence suggests that the magma responsible for the diorite-granite series is in many cases primarily granitic. The granitization phenomena seen in the Sveco-Fennides of Southern Finland and in the exposed roots of ancient orogenic belts the world over make it abundantly clear that the rising magmas producing migmatites are largely composed of the constituents of quartz and alkali felspars. Potash is often very abundant (Wegmann and Kranck, 1931) in this " ichor ", as Sederholm calls it, and while this fact is consistent with the refusion hypothesis, it presents a serious difficulty to those who would derive it from a granodioritic or more basic magma. All recent detailed studies of " granite " complexes record contamination of relatively pure granite magma by either sediments or igneous rocks of more basic composition, or both. It has been proved conclusively by Brammall and Harwood (1932) that many characters possessed by the Dartmoor granites, and conceivably inherited from a more basic ancestral magma, were really acquired from assimilated materials. Thomas and Campbell Smith (1932), who have made an admirable study of the Trégastel-Ploumanac'h complex and its xenoliths, also point out that the bulk of the hybrid mass there exposed consists of monzonitic and tonalitic types similar to those intimately associated with granites such as the Old Red Sandstone granites of Scotland and elsewhere ; these authors tentatively suggest " that tonalitic and monzonitic margins to granite masses may be due to the hybridizing influence of the granite magma upon an earlier plutonic rock of basic or ultrabasic composition which once formed part of the same complex, but of which all superficial traces may have disappeared ". The two papers here referred to contain many references to other acknowledged examples of basification of granite magma (Shap Fells; Bodmin Moor: Loch Doon. Isle of Man: Auch'uaine, Sutherland: Viborg, Finland). Another notable example has been recently described from Jersey (Wells and Wooldridge, 1931). The earlier work of Michel-Lévy, Lawson, Sederholm, Daly, Cole, Mennell, and others in this field should not be overlooked. Sederholm has provided a history and bibliography of the subject (1923, p. 7, et seq.).

Between granitized basic rocks and basified granites there is, of course, every gradation. The important conclusion that emerges is that the initial magma was granitic in both cases. This being now conclusively demonstrated, it becomes probable that in the corresponding volcanic series of orogenic belts the andesites and dacites appear with the basalt-rhyolite association not as intermediate members of a liquid line of descent but, in part at least, as products of basification of granite magma. The rarity of andesites that are not conspicuously porphyritic is in keeping with this deduction. Basalts and rhyolites contain only traces or small amounts of BaO and SrO, whereas in andesites and dacites (as in the corresponding plutonic types) these oxides are generally at least twice as abundant (Holmes and Harwood, 1932, p. 423). Geochemical evidence of this kind suggests assimilation of shales on a considerable scale (Brammall, 1931, p. 211), and the characteristic association of rhombic pyroxenes with andesites points to a similar conclusion.

There are good reasons why such intermediate rocks should be common in orogenic belts rather than in kratogenic regions. In the former, the granite magma rises from far greater depths, and being therefore endowed with much more heat it has a greater capacity for digesting (i) basic materials in the Upper Intermediate and Granitic layers, and (ii) basic sediments and igneous rocks in the sedimentary layer which in orogenic belts is thick to begin with and is made still thicker by folding.

THE ACIDIFICATION OF BASALTIC MAGMA.

Basic magma may react with granitic and sedimentary rocks with which it comes into contact and mix with co-existing acid magma whenever circumstances permit. Variation suites of rock-products ranging from acid to basic are then the inevitable result of differentiation. Some dioritic and andesitic rocks may be referable to this bigeneric process of assimilation and differentiation. In particular, as the late Dr. J. W. Evans taught in his lectures, norites and pyroxene-andesites may sometimes be due to the absorption of argillaceous sediments by basaltic magma. Read has directed attention to the association of alumina-rich xenoliths and noritic rocks (1931, p. 453). He points out that "the addition of this alumina-rich material to the basic magma would result in the increase of the amount of magnesia in the pyroxene and of anorthite in the plagioclase, that is, in the production of a norite", and he joins forces with Bowen (1928, p. 214) in remarking that "if there were not so many slates there would not be so many norites".

In kratogenic regions intermediate rocks, produced on a small scale only, may owe their characters to admixture of acid material with basaltic magma. The "andesitic" tholeiites (e.g. Acklington and Cleveland types) of the Mull–North of England suite of dykes may be examples (Holmes and Harwood, 1930, p. 49). The peculiar rocks of the craignurite series of Mull may be others (Mull Memoir).

Of particular interest is the question of the origin of the interstitial micropegmatite and pegmatitic segregations in dolerites. Writing of the Jotnian olivine-diabase of Säppi Island, West Finland, Eskola remarks: "No matter whether the pegmatoid pipes on Säppi have been derived from assimilated materials or from substances originally present in the magma, they in any case were liquid at the crystallization of the diabase and their mode of occurrence illustrates the way they have separated out from the rock" (1932, p. 472). This occurrence, which I had the pleasure of visiting last year under the guidance of Professor Eskola, presents in a most conspicuous way a problem which is of fundamental importance in petrogenesis. Does the pegmatitic material represent:

(*a*) A residual liquid from parental basaltic magma?

(*b*) A residual liquid from basaltic magma acidified by granitic material?

(*c*) Or a granitic refusion-product more or less basified by assimilation reactions with the olivine-diabase through which it passed?

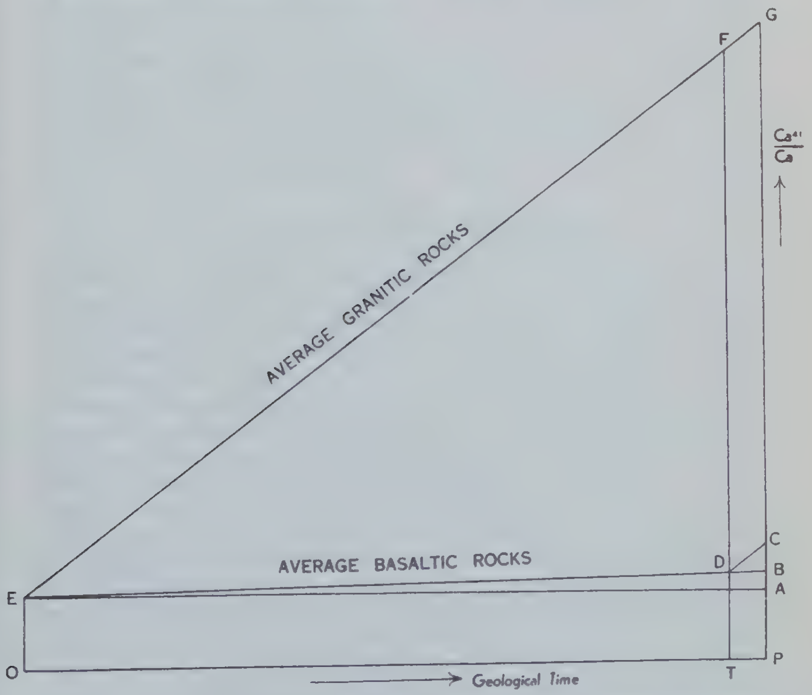
In attempting to answer such questions it has occurred to me that they, and indeed the whole problem of the pre-magmatic history of igneous rocks in general and of granites in particular, may be solved by an appeal to the accumulation during geological time of the disintegration product of potassium.

A NEW KEY TO PETROGENESIS.

So far, the arguments in favour of the origin of granite by refusion have depended on a convergence of circumstantial evidence. Decisive criteria for determining whether a specimen of (say) Tertiary granite, granophyre, or rhyolite originated by (i) refusion from pre-existing granite or (ii) differentiation from basaltic magma would certainly be most welcome. What is required is a method of determining whether the pre-magmatic source of the rock was granitic or basaltic, and I believe that the possibility of obtaining such evidence is now definitely in sight.

It is now established that K^{41} disintegrates by loss of a beta-particle to Ca^{41}. In granitic rocks the ratio K/Ca averages about 2·7, whereas in basaltic rocks this ratio is about 1/10. Consequently, the proportion of Ca which is Ca^{41}, must have increased during geological time something like twenty-seven times as fast in granitic as in basaltic materials. In some granites the increase in Ca^{41} must have been very much greater than this.

In the adjoining figure let OE represent the ratio Ca^{41}/Ca at the time when the separation of the granitic and basaltic layers took place in the newly-formed earth. The ratio would be the same in both kinds of material at the time of the schism, and preliminary tests indicate that it was probably small compared with the values since achieved in granites. Let EG represent the increase of Ca^{41}/Ca in granitic materials and EB the much slower increase of this ratio in basaltic materials.



Suppose the point T marks the initiation of a granitic magma during Tertiary time. If the magma were produced by refusion of material at F, which had been essentially granitic throughout geological time, the present value of the ratio Ca^{41}/Ca would fall somewhere near G. If the magma were a derivative of basaltic magma at D, the ratio in the resulting granitic rock would fall near C. The ratio for the associated basaltic rocks themselves would fall near B. Now since the age of the earth is of the order 2,000 million years, BG should be at least forty times BC. This difference is so considerable that it should be readily detectable by the magneto-optic method of isotope determination discovered by Dr. F. Allison, of Auburn, Alabama (1932). The value of Ca^{41}/Ca for Tertiary basalts should fix the point B, and the value for Lewisian gneiss or other ancient Pre-Cambrian granite should fix a point within the range of which G is a representative. The value found for (say) Tertiary granophyre should then be near B if the rock is a basaltic differentiation product, while if the rock is due to refusion of granite the value should be very considerably greater than B and near G.

Dr. Allison has generously consented to try out the suggested method by testing a suite of carefully selected analysed rocks which have been forwarded to him. If the method proves to be practicable, and I can see no reason why it should fail, it will supply a master key for unlocking many of the pre-magmatic secrets of petrogenesis.[1] However, until some actual results are available, it would be premature to discuss the anticipated applications of the method to problems like those of the Säppi pegmatoid pipes, which may prove to be less tractable until a good deal of data has been accumulated.

THE ORIGIN OF PERIDOTITES.

On the assumption of basaltic parentage, peridotites are regarded as accumulations of crystals of early-formed olivines, pyroxenes, etc., or as products of magmas generated by the sinking and refusion of such crystals. The first of these processes is reasonably well established by many examples. The second process, however, is theoretically improbable because in sinking, the minerals come under conditions of higher pressure whereby their fusion points are raised. In purely basaltic reservoirs, this rise of fusion point is likely to be greater than the rise of temperature, and in such a case no refusion could occur (Holmes, 1931, Fig. 2). If a glassy substratum exists, this relation can no longer be true at the depths where the glassy state normally begins to appear. Refusion would therefore be possible only in the substratum or in the deeper, peridotitic, levels of crustal reservoirs maintained as magma by heat from the substratum. But here, peridotite magma is already available: in part it may be the "primary" magma of the substratum itself, in part the product of refusion of the crystalline portion of the Lower layer. Thus, if there be evidence of the existence of peridotite magmas, our argument suggests that the latter must have come from depths below the basaltic layer where they would owe nothing to the pre-existence of basaltic magma.

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[1] It is worthy of note that when the rate of disintegration of K^{41} is accurately known, such lines as EG and EB and therefore their intersection at the point E will be determinable. E corresponds as exactly as one could wish with the date of the earth's origin, and its determination will therefore provide for the first time a direct estimate of the age of the earth. When suitably corrected, the values of Ca^{41}/K for potash felspars will give a measure of the age of the granites containing them. It will then be possible to build up a geological time-scale, to fix the ages of granites of unknown geological position and to effect a detailed correlation of pre-Cambrian rocks from continent to continent in far more detail than is possible at present.

The remarkable dunite bodies and later pipes of hortonolite-dunite that cut the lower part of the Norite Zone of the Bushveld Complex have clearly existed as magmas (Wagner, 1929, p. 86). Wagner believed that the dunite magma was a residual magma produced by crystallization-differentiation from the basaltic magma responsible for the rocks of the Norite Zone, but I know of no evidence to support this view which, moreover, is completely at variance with experience elsewhere. It is surely worthy of consideration that the production of the granitic and basaltic magmas of the Bushveld was accompanied by the production and ascent of peridotite magma from greater depths.

Wagner himself suggested that the parent magma of the kimberlite pipes of South and Central Africa was generated from a deep-seated zone of primary peridotite, and that the various types of kimberlite were differentiation products from that magma (1914, p. 117, and 1928, p. 146).

Important evidence of the injection into the crust of peridotite magma is provided by the Carboniferous "Serpentine Belt" of Eastern Australia described by Benson in a long series of papers (*Proc. Linn. Soc. N.S.W.*, 1913 to 1920; see also Benson, 1926, pp. 37–40). The intrusion was preceded by rhyolites and andesites and followed by quite subsidiary gabbros. *This sequence is fatal to the idea of a basaltic parentage.* An even greater belt of peridotite and serpentine which in many places seems to be equally independent of a basaltic origin, can be traced at intervals throughout the Alpine-Himalayan system and onwards through the Burman arc to the Philippines on the one hand, and to New Guinea, New Caledonia, and New Zealand on the other.

It is probable that the Ca^{41} method already described may serve to discriminate between peridotites that are crystal accumulates of basaltic origin and those derived from the Lower layer. The former should have a Ca^{41}/Ca ratio characteristic of basaltic rocks, whereas the latter should have a lower ratio, since the K/Ca ratio for peridotites is less than that for basaltic rocks.

THE ORIGIN OF ALKALI ROCKS.

Writing on this subject, Shand has recently stated: "Up to a certain point, Daly's theory has been proved to be correct; beyond that point the choice lies between Daly's theory and no theory at all" (1930, p. 426). I propose to show that our position is not really quite so hopeless. Starting with basaltic magma alone, Daly found it impossible to imagine adequate causes for desilication and relative enrichment in alkalis so long as the magma remained juvenile. He therefore postulated absorption of carbonate materials as the condition responsible for the evolution of "alkali" magmas. Shand has extended the hypothesis to include the production, by differentiation, of a residual alkali-granite magma, which, by reaction with carbonate-rocks, evolves a foyaite magma from which in turn ijolite may be generated by further reaction with carbonate rocks.

Although the "limestone-assimilation" theory has many attractive features, I cannot admit that it provides a general solution of the problem. As Smythe has pointed out (1927, p. 540), the association of alkali rocks with carbonate rocks is far from being systematic, and conversely there are innumerable intimate associations of carbonate rocks with igneous bodies that are entirely free from "alkali" characters. Kranck has pertinently observed (1928, p. 83) that the occurrence of calcite in alkali rocks is as likely to be a consequence of the primary presence of CO_2 in their magmas as it is to depend on the absorption of limestone. Backlund has just published (1932) a comparative study of composite alkali bodies of the agpaitic suite which penetrate country rocks of granitic composition visibly free from limestones.[1] Sequences such as ijolite—foyaite—alkali-syenite—alkali-granite—are characteristic, and Backlund suggests that ijolite magma is the immediate parent, and that the associated types have been generated by reaction with granite. In some of these occurrences (Ilimausak) carbonates are lacking, while in others (Fen, Almunge, Umptek) carbonate deposits accompanied by apatite and iron ores appear as late-magmatic or hydrothermal products. If we begin with an ijolite magma derived from a source capable of providing juvenile CO_2, then the limestone assimilation theory loses much of its force, even in regions where limestone happens to be present, as sometimes it must, among the country rocks.

A clue to the origin of the ijolite magma is provided by the circumstances that the alkali rocks have marked geochemical peculiarities which relate them to kimberlite and presumably, therefore, to a magmatic ancestry in which peridotite magma plays a parental part (Holmes and Harwood, 1932, p. 425). Recent work on the potash-rich volcanic rocks of Uganda has provided evidence that supports the inference of a peridotitic parentage. The association of olivine-leucitite, leucitite, melilite-basalt and biotite-pyroxenite in the vents east and south-east of Ruwenzori, together with the absence of granitic and basaltic types and their derivatives, indicates that a hypothesis of granitic or basaltic parentage is there untenable. It is suggested that the magmas of mica-peridotites and olivine-leucitites are formed essentially by the abstraction of the constituents of eclogite and dunite from a primary peridotite magma under conditions of high pressure ; and that the magmas of melilite-basalt are formed under conditions of somewhat lower pressure by the early crystallization and separation of olivine and enstatite. Evidence of the separated crystalline phases is found in the magmatic eclogite nodules of kimberlite pipes and in the enstatite phenocrysts of the melilite-basalt tuffs of Uganda. The assemblage of materials to be abstracted from primary peridotite magma to give (say) nephelinite or ijolite magma includes olivine, enstatite, and diopside, and possibly phlogopite.

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[1] Certainly it ought not to be assumed that concealed bodies of limestone are necessarily absent from the depths beneath a granite-gneiss complex, even when no limestone is visible at the surface. In Mozambique there are rare lenticles of crystalline limestone in the gneisses, and I have described a particularly clear case of interaction between granite magma and one of these (*QJGS.*, lxxiv, p. 60). The changes that occurred imply the liberation of alkalies and carbon dioxide, and it is quite conceivable that in appropriate circumstances such materials may have played a part in the genesis of alkali rocks. But while admitting the possibility, it must not be forgotten that alkali rocks are rare in orogenic regions and that alkaline solutions that may have been liberated by interaction between granite magma and limestone are likely to have been used up in hydrothermal changes such as sericitization.

This hypothesis, combined with Backlund's work, gives promise of a reasonable explanation of a wide suite of alkali rocks by reaction between (i) soda- and potash-rich residual magmas from primary peridotite, and (ii) country rocks belonging to the granitic layer. Similar reaction with the materials of the basaltic layer may be expected also to take place and to give rise to plagioclase-bearing types such as the tephrites, basanites, and theralites, with phonolites and nepheline-syenites as later products of differentiation. The possibilities of magmatic mixing and assimilation combined with differentiation are obviously as varied as the phenomena to be accounted for. The Ca^{41} method may afford a means of testing the validity of the hypothesis here advocated.

CONCLUSIONS.

From the observational fact that basaltic magma fails to produce rhyolites, dacites, or andesites in the inner Pacific, it is inferred that the magmas of these rocks are not normally products of differentiation of basaltic magma. The association of acid and basic rocks in kratogenic regions and the "contaminated" characters of dioritic and granodioritic rocks in orogenic belts suggest that granite magma arises independently of basaltic magma except in so far as the latter serves as a carrier of heat. Peridotites with a basaltic ancestry are well known, but peridotite magmas cannot be accounted for otherwise than by refusion. The conditions that would favour the refusion of crystal accumulations from basaltic magma would also suffice to produce peridotite magma from the upper part of the Lower layer. Moreover, felspar-free alkali rocks, such as kimberlite, leucitite, ijolite, and nephelinite, cannot be derived from granitic or basaltic magmas, whereas a plausible explanation of their genesis is forthcoming if a peridotitic parentage be assumed.

Thus, in satisfactory agreement with the geophysical interpretation of crustal structure, the evidence of comparative petrology leads us to conclude that at least three main types of parental magmas should be recognized: ultrabasic, basic, and acid. From each of these a wide variety of rock types can be produced by the operation of additive and subtractive [1] processes of differentiation. The latter involve varying degrees of separation of solid, liquid, and gaseous phases, and the composition and order of appearance of these phases vary with the PT conditions of the magma and its content of volatiles. Slow cooling under confined and high pressure conditions may be expected to give a rock series very different from that produced by more rapid cooling under low pressure.

A further cause of variation is introduced where magmas of different composition mix, and a still greater extension of the diversity of types becomes possible when a magma reacts with its country rock (including earlier products of the same igneous cycle), and both assimilation and differentiation proceed hand in hand. Mixed types of another category are also conceivable. The solid phases of one magma (say granitic), whether due to crystallization or reaction with xenoliths, may sink and come into contact with an underlying magma or its residual liquor. Some of the lamprophyres—rocks in which extremes of differentiation appear to meet—may owe their genesis to some such process, as Miss Doris L. Reynolds has suggested in her illuminating study of the lamprophyres of the Ards Peninsula (1931, p. 159, et seq.).

Still another cause of variation may be looked for in differential refusion, for the early low-temperature magmas will differ from those produced later as refusion becomes complete. Eskola has suggested that "If the theory of re-fusion and squeezing out of the lowest melting portion from different kinds of rocks in orogeny is right, then many highly metamorphic crystalline schists must have been changed in composition by the loss of low-melting substances" (1932, p. 478). Several authors have directed attention to the significant fact that soda appears to be liberated during the formation of mylonites and schists (Wiman, 1932, p. 156). This observation may be correlated with the characteristic appearance of rocks of the spilitic suite during the development of geosynclines, and with my own suggestion that the puzzling characters of the spilitic suite may be due to differential fusion of rocks under the active stress that must accompany stretching (Holmes, 1927, p. 277). Whether this hypothesis be true or not, it must not be overlooked that partial fusion in a system under stress is likely to generate magmas of abnormal composition as compared with those produced by passive refusion.

In conclusion, I wish to add that the scheme of petrogenesis boldly sketched in this paper is not put forward in any dogmatic spirit: it merely erects tentative conclusions as wickets to be bowled at.

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[1] These terms have been proposed by Peacock.

REFERENCES.

ALLISON, F. (1932). "Magneto-Optic Method of Analysis as a New Research Tool," *Indust. and Eng. Chem.*, iv, 9–12.

BACKLUND, H. G. (1932). "On the Mode of Intrusion of Deep-seated Alkaline Bodies," *Bull. Geol. Inst. Upsala*, xxiv, 1–24.

BENSON, W. N. (1926). "The Tectonic Conditions accompanying the Intrusion of Basic and Ultrabasic Rocks," *Mem. Nat. Acad. Sci.*, Washington, xix, No. 1, 1–90.

BOWEN, N. L. (1928). *The Evolution of the Igneous Rocks.* Princeton.

BRAMMALL, A. (1931). "The Genesis of Ores in Relation to Petrographic Processes," *Rep. Brit. Assoc.*, London, 385–7.

BRAMMALL and HARWOOD, H. F. (1932). "The Dartmoor Granites: Their Genetic Relationships," *QJGS.*, lxxxviii, 171–237.

DALY, R. A. (1914). *Igneous Rocks and their Origin.* New York.

ESKOLA, P. (1932). "On the Origin of Granitic Magmas," *Min. Pet. Mitt.*, xlii, 445–81.

FENNER, C. N. (1931). "The Residual Liquids of Crystallizing Magmas," *Min. Mag.*, xxii, 539–60.

GREIG, J. W., SHEPHERD, E. S., and MERWIN, H. E. (1929). *Bull. Geol. Soc. Am.*, xl, pp. 94–5. See also Annual Report of the Director, Geophysical Laboratory. *Year Book of the Carnegie Institution, Washington*, for 1930–31, 75–100.

GUTENBERG, B. (1932). "Travel Time Curves at Small Distances, and Wave Velocities in Southern California," *Gerlands Beiträge*, xxxv, 6–50.

GUTENBERG, B., and RICHTER, C. F. (1931). "On Supposed Discontinuities in the Mantle of the Earth," *Bull. Seis. Soc. Am.*, xxi, 216–22.

HOLMES, A. (1915). "The Origin of Igneous Rocks," *Science Progress*, 67–73.

—— (1926). "Contributions to the Theory of Magmatic Cycles," GEOL. MAG., LXIII, 306–29.

—— (1927). "Some Problems of Physical Geology and the Earth's Thermal History," GEOL. MAG., LXIV, 263–78.

—— (1931). "The Problem of the Association of Acid and Basic Rocks in Central Complexes," GEOL. MAG., LXVIII, 241–55.

HOLMES, A., and HARWOOD, H. F. (1929). "The Tholeiite Dikes of the North of England," *Min. Mag.*, xxii, 1–52.

—— (1932). "The Petrology of the Volcanic Fields East and South-East of Ruwenzori, Uganda," *QJGS.*, lxxxviii, 370–442.

JEFFREYS, H. (1929). *The Earth.* Second edition, Cambridge.

KRANCK, E. H. (1928). "On Turjaite and the Ijolitic Stem of Turja, Kola," *Fennia*, li, No. 5, 1–104.

KROKSTRÖM, T. (1932). "On the Ophitic Texture and the Order of Crystallization in Basaltic Magmas," *Bull. Geol. Inst. Upsala*, xxiv, 197–216.

NIGGLI, P. (1923). "Der Taveyannazsandstein und die Eruptivgesteine der jung-mediterranean Kettengebirge," *Schweiz. Min. Pet. Mitt.*, iii, 169–275.

POOLE, J. H. J. (1930). "The Thermal Instability of the Earth's Crust" (II), *Sci. Proc. Roy. Dublin. Soc.*, xix, N.S. No. 32, 385–408.

READ, H. H. (1931). "On Corundum-Spinel Xenoliths in the Gabbro of Haddo House, Aberdeenshire," GEOL. MAG., LXVIII, 446–53.

REYNOLDS, Doris L. (1931). "The Dykes of the Ards Peninsula, Co. Down." GEOL. MAG., LXVIII, 97–111 and 145–65.

SEDERHOLM, J. J. (1907). "On Granite and Gneiss," *Bull. Geol. Comm. Finlande*, No. 23. See also "On Migmatites" (II), ibid., No. 77.

SHAND, S. J. (1930). "Limestone and the Origin of Felspathoidal Rocks," GEOL. MAG., LXVII, 415–27.

SMYTHE, Jr. C. H. (1927). "The Genesis of Alkaline Rocks," *Proc. Am. Phil. Soc.*, lxvi, 535–80.

THOMAS, H. H., and SMITH, W. CAMPBELL (1932). "Xenoliths of Igneous

Origin in the Trégastel-Ploumanac'h Granite, Côtes du Nord, France," *QJGS.*, lxxxviii, 274–96.

Wagner, P. A. (1914). *The Diamond Pipes of South Africa.* Johannesburg.

—— (1928). "The Evidence of the Kimberlite Pipes on the Constitution of the Outer Part of the Earth," *S. Af. Journ. Sci.*, xxv. 127–248.

—— (1929). *The Platinum Deposits and Mines of South Africa.* Edinburgh.

Wegmann, C. E., and Kranck, E. H. (1931). "Beiträge zur Kenntnis der Svecofenniden in Finnland," *Bull. Comm. Geol. Finlande.* No. 89.

Wells, A. K., and Wooldridge, S. W. (1931). "The Rock Groups of Jersey, with Special Reference to Intrusive Phenomena at Ronez," *Proc. Geol. Assoc.*, xlii, 178–215.

Wiman, E. (1932). "Studies of some Archaean Rocks in the Neighbourhood of Uppsala, Sweden, and of their Geological Position." *Bull. Geol. Inst. Upsala*, xxiii, 1–170.

REVIEWS.

A Text Book of Mineralogy. With an extended Treatise on Crystallography and Physical Mineralogy. By Edward Salisbury Dana. Fourth Edition, revised and enlarged, by William E. Ford. pp. xi + 851, with 1089 figures. New York: John Wiley & Sons. 1932. Price, 34*s*.

The third edition of this well-known textbook (1922) contained 720 pages. In this fourth edition the book is enlarged to 851 pages. The essential changes are as follows: In Part I on Crystallography, a section of 17 pages on crystal structure and X-ray methods has been added, while a further addition is a section (18 pages) on the origin, mode of occurrence, and association of minerals—reproduced with only minor changes from Dana's *Manual of Mineralogy* (1929). Simple statements of the result of the investigation of mineral structures by X-ray investigation have been included in the description of the more important mineral groups.

To Part V the descriptions of about 220 new species have been added. This part has been entirely revised, and purports to present a brief but complete statement of the important facts now known about all well-defined mineral species. It is doubtful whether this change of policy in an elementary textbook is well advised, usurping as it does the function of Dana's *System*, a new edition of which is already in preparation. Space devoted to the description of the rarer minerals might well have been devoted to a clearer exposition of the crystal structure of the more important minerals. Diagrams illustrating atomic arrangements are all too few and are wholly relegated to the section on crystallography.

Though many of the chemical formulae of minerals have been brought up to date, the revision is not systematic, e.g. under the amphibole group, though reference is made to the recent work on the composition and structure of the hornblendes, yet anthophyllite and cummingtonite are still written as $MgSiO_3$, $(Mg,Fe)SiO_3$.

In view of the importance of the subject some space should be devoted to the laboratory investigation of opaque ores, particularly the methods of examination by reflected light.

In the descriptions of the individual minerals there is room for improvement in the sections under *Obs.* (Observations on Occurrence, etc.) and *Pyr.* (Pyrognostics), particularly in regard to data of mineral synthesis and paragenesis. Any modern textbook of mineralogy might be expected to draw upon the quantitative data assembled by the Geophysical Laboratory workers and the studies of petrologists on mineral parageneses and it is to be hoped that in a future edition the physico-chemical side of mineralogy will be emphasized at the expense of long lists of mineral localities which more suitably find a place in larger treatises. Some errors and misprints of the third edition have been corrected, but a number still survive. The statement that u, v, w " represent the reciprocals of the values of the co-ordinates " (p. 62) is incorrect; the vertical axis is an axis of tetragonal symmetry in *five* of the classes of the tetragonal system (p. 93). The discussion of the relations between the two forms of notation in the hexagonal system (p. 136), originally in error, has been recast, but a new mistake appears in the statement $i = h + k$. A particularly tiresome misprint in a book used largely by students commencing goniometry is perpetuated in the value 89° 49′ instead of 86° 49′ for the angle ll' in topaz (p. 613).

C. E. T.
F. C. P.

BAUXITE AND ALUMINOUS LATERITE. By CYRIL S. FOX. pp. xxxi + 312. London: Crosby Lockwood and Son. 1932. Price, 30*s.* net.

THIS is a second edition of the author's *Bauxite* published in 1927; and is, indeed, very largely a reprint of that book, as is revealed by the persistence of errors in the text and index. New matter is found in the Introduction and chapters x and xi.

In the Preface and Introduction to this second edition the author has much to say that is of scientific interest, whether we agree with him or not. In his Geological Survey of India Memoir on " The Bauxite and Aluminous Laterite Occurrences of India " (vol. xlix, part 1, 1923), the author stated that the name " bauxite " is best applied to those varieties of laterite sufficiently rich in alumina to be used as aluminium ores; but he now wishes to restrict it to the French or European type of material and to call bauxite of true lateritic origin " aluminous laterite ", presumably whether it can be worked as aluminium ore or not. The French or European type is also referred to as the " *terra rossa* type ", and is considered, if the reviewer understands the author correctly, to be a true sediment and to have been in its original condition grey and often pyritic (p. xxv).

It is further stated (p. xxxi) that there appears to be a preponderance of aluminium monohydrate in bauxite as defined in this volume, and a preponderance of the trihydrate in the lateritic type.

" *Terra rossa* " is used by the author to denote the weathered red clays of limestone and dolomitic rocks found on such rocks ; *roterde* to him means the red clay of basaltic or basic igneous rocks ; whereas " the words *red clay* should in general be applied to material of uncertain origin ". An obvious comment on the proposed use of the last term is that " red clay " is generally used for a widespread deep sea deposit.

However strong the grounds may be for considering that the French or European type, on the one hand, and the Indian or lateritic type, on the other, originated in different ways, the author's proposed new divisions may be received without enthusiasm in that they introduce further confusion into a subject already confused. H. and F. J. Warth regarded laterite as bauxite in varying degrees of purity. Mr. T. Crook, in his *Economic Mineralogy* (p. 152), says that the term bauxite in a mineralogical sense should be applied to the characteristic ingredient of laterites. Dr. Fox now wants us to drop the word bauxite in connection with laterite. Chemically, bauxite appears to be far from a definite substance, and if any further change in nomenclature is desirable would it not be well to call that which has a preponderance of the monohydrate "diaspore," and that which has a preponderance of the trihydrate "gibbsite" ?

As in his Geological Survey of India Memoir, Dr. Fox again remarks on the rarity of bauxite enrichments in Indian laterite (p. 188). Many would be grateful if Indian geologists would give us analyses of Buchanan's type rocks from the type localities that he visited in 1800 and described in 1807. They would throw light on the necessity of considering aluminium hydrate a characteristic ingredient.

It is a matter for regret that the author was unable to bring the bibliography up to date ; but this volume still retains the value of the earlier edition in presenting a very interesting account of the occurrence, mining, preparation, and uses of bauxite, and of the aluminium industry, which is a model of successful control.

J. B. S.

CORRESPONDENCE.

THE GENESIS OF LEUCITE AND MELILITE ROCKS.

SIR,—I have read with great interest the account given by Drs. Holmes and Harwood of the volcanic rocks near Ruwenzori (*Quart. Jour. Geol. Soc.*, lxxxviii, 370). The descriptive part of this paper is altogether admirable, but I find myself in two minds regarding the theoretical part. Not for the first time, I am torn between admiration of an ingenious theory and inability to believe it. Dr. Holmes will have it that leucite and melilite rocks are differentiates of the primary peridotite magma that is assumed to underlie the granitic and basaltic skins of the earth. This peridotite zone is generally thought to begin some 40 miles beneath the surface and to extend down to a depth of about a thousand miles. Dr. Holmes shows clearly that if this magma sheds enough olivine and eclogite it will leave a residue having approximately the composition of olivine-leucitite, and that if it sheds olivine and enstatite the residue will approximate to melilite-basalt. Given a magma of a sufficiently accommodating disposition, these results might indeed be realized; but it seems to me that invoking the aid of a world-wide magma in order to explain a local rock-facies is dangerous. It is like using a steam-roller to crack a nut; you cannot limit its action and it is certain to crack a whole lot of other things besides the nut. In short, if the world-wide peridotite magma behaves as Holmes supposes, *it must do so at similar depths all round the world, not only in Uganda, and olivine-leucitites and melilite-basalts should be the commonest instead of the rarest of rocks.* That such rocks are in general most rare, although abundant at a few localities, is to my mind the clearest proof that they are due to a local cause, not a world-wide one.

Dr. Holmes claims, on the basis of a few determinations of BaO, SrO, and other minor chemical constituents, that there is a "community of geochemical associations" between leucite-melilite rocks and mica-peridotite. I wonder whether that most accurate analyst, Dr. Harwood, shares his colleague's faith in the validity of this argument? Most of the minor constituents to which Holmes alludes are present in such trivial quantities as to affect only the second decimal place, and accurate determination of such minute quantities is not possible by gravimetric methods when one uses only a half or one gram of rock. I suggest that the difference, to which Holmes refers, in the strontia content of rocks from eastern Australia and southern Rhodesia is just as likely to be characteristic of a particular analyst or a particular batch of reagents as of the rocks themselves. Until the minor constituents of rocks are determined in samples at least ten times as large as those ordinarily used in rock analysis, it will be unwise to base any far-reaching deductions on the proportions of these constituents.

Dr. Holmes refers briefly to Daly's hypothesis of limestone-assimilation as an alternative to his own theory, but rejects it on the twofold ground that no limestone is known in the Ruwenzori region and that reaction with limestone " provides no way of ensuring a regional excess of K_2O over Na_2O ". The first point is not conclusive ; nobody travelling over the red granite country of the Transvaal would ever imagine that there was a massive limestone several miles beneath the granite ; but there is. Holmes describes blocks of melanite-pyroxenite and tremolite-amphibolite among the ejectamenta of the Ruwenzori volcanoes ; there are no minerals more characteristic of limestone contacts than melanite and tremolite. It would be extravagant to claim that these few specimens prove anything about the genesis of the lavas with which they are associated, but at least they form a more solid basis for speculation than the comparison of infinitesimal amounts of the rarer oxides. As for Holmes' second point, I have shown in my paper on the granite-syenite-limestone contact of Palabora (*Trans. Geol. Soc. S. Africa*, xxxiv, 81) that rocks extremely rich in K_2O and almost deprived of Na_2O have been formed in that region in consequence of reaction between granitic magma and limestone.

I hope Dr. Holmes will take my criticism in the spirit in which it is offered, and that when he and the officers of the Uganda Geological Survey come to describe the leucite rocks of the Bufumbiro volcanoes they will not allow the fascinating game of speculating about the earth's interior to blind them to indications that may lie just beneath their feet.

S. J. SHAND.

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